Conformal Ablative Thermal Protection System for Planetary and Human Exploration Missions:

An update of the Technology Maturation Effort Funded by
NASA's Game Changing Development Program

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NASA has identified the need to develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable. Furthermore, the Game Changing Development Program is a primary avenue to achieve the Agency's 2011 strategic goal to "Create the innovative new space technologies for our exploration, science, and economic future." The National Research Council (NRC) Space Technology Roadmaps and Priorities report highlights six challenges and they are: Mass to Surface, Surface Access, Precision Landing, Surface Hazard Detection and Avoidance, Safety and Mission Assurance, and Affordability. In order for NASA to meet these challenges, the report recommends immediate focus on Rigid and Flexible Thermal Protection Systems.

Rigid TPS systems such as Avcoat or SLA are honeycomb-based and Phenolic Impregnated Carbon Ablator (PICA) is manufactured in the form of tiles. The honeycomb systems are manufactured using techniques that require filling of each (3/8" cell) by hand, and in a limited amount of time all of the cells must be filled and the heatshield must be cured. The tile systems such as PICA pose a different challenge as the low strain-to-failure and manufacturing size limitations require large number of small tiles with gap-fillers between the tiles. Recent investments in flexible ablative systems have given rise to the potential for conformal ablative TPS.

A conformal ablator TPS over a rigid aeroshell has the potential to solve a number of challenges faced by traditional rigid TPS materials. The high strain-to-failure nature of the conformal ablative materials will allow integration of the TPS with the underlying aeroshell structure much easier and enable monolithic-like configuration and larger segments (or parts) to be used. By reducing the overall part count, the cost of installation (based on cost comparisons between blanket and tile materials on shuttle) should be significantly reduced. The conformal ablator design will include a simplified design of seams between gore panels, which should eliminate the need for gap filler design, and should accommodate a wider range of allowable carrier structure imperfections when compared to a rigid material such as PICA.

The Conformal Ablative TPS (CA-TPS) development project has the goal to develop and deliver a TRL 5-6 conformal TPS capable of at least 250 W/cm^2 for missions such as Mars Science Laboratory (MSL) or Commercial Orbital Transportation Systems (COTS) missions. The capability goals for the conformal TPS are similar to an MSL design reference mission (~250 W/cm^2) with matching pressures and shear environments.

As described at IPPW-10, in FY12, the CA-TPS element focused on establishing materials requirements based on MSL-type and COTS Low Earth orbit (LEO) conditions ($q \sim 250\ W/cm^2$) to develop and deliver a conformal ablative TPS. This involved downselecting, manufacturing and testing two of the best candidate materials, demonstrating uniform infiltration of resins into

baseline ~2-cm thick carbon felt, selecting a primary conformal material formulation based on novel arc jet and basic material properties testing, developing and demonstrating instrumentation for felt-based materials and, based on the data, developing a low fidelity material response model so that the conformal ablator TPS thickness for missions could be established. In addition, the project began to develop Industry Partnerships. Since the nominal thickness of baseline carbon felts was only ~2-cm, a partnership with a rayon felt developer was made in order to upgrade equipment, establish the processes required and attempt to manufacture ~10-cm thick white goods. A partnership with a processing house was made to develop the methodology to carbonize large pieces of the white goods into ~7.5-cm thick carbon felt.

In FY13, more advanced testing and modeling of the downselected conformal material was performed. Material thermal properties tests and structural properties tests were performed. The first 3 and 4-point bend tests were performed on the conformal ablator as well as PICA for comparison and the conformal ablator had outstanding behavior compared to PICA. Arc jet testing was performed with instrumented samples of both the conformal ablator and standard PICA at heating rates ranging from 40 to 400 W/cm^2 and shear as high as 600 Pa. The results from these tests showed a remarkable improvement in reducing the thermal penetration through the conformal ablator when compared to PICA's response. The data from these tests were used to develop a mid-fidelity thermal response model. Additional arc jet testing in the same conditions on various seam designs were very successful in showing that the material could be joined with a minimum of adhesive and required no complicated gap and gap filler design for installation. In addition, the partnership with industry to manufacture thicker rayon felt was very successful. The vendor made a 2-m wide by 30-m long sample of 10-cm thick rayon felt. When carbonized, the resulting thickness was over 7.5-cm thick, nearly 4 times the thickest off-the-shelf carbon felt.

In FY14, the project has initiated a partnership with another vendor to begin the scale-up manufacturing effort. This year, the vendor will duplicate the process and manufacture at the current scale for comparison with NASA-processed materials. Properties testing and arc jet testing will be performed on the vendor-processed materials. Planning for manufacturing large, ~1-m x 1-m, panels will begin as well. In FY15, the vendor will then manufacture large panels and the project will build a ~2-m x 2-m Manufacturing Demonstration Unit (MDU).